PRESIDENT'S MESSAGE

by Arun Shukla, SEM President

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SEM President
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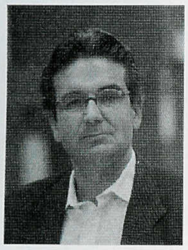
Experimental investigation of dynamic failure of materials has always been a challenging problem for researchers and practicing engineers. Since the dynamic problems are analytically more difficult to solve and experimentally more challenging to study, there has always been a dearth of knowledge in this field. Our next article in the series "Trends in Experimental Mechanics" talks about the challenges and length scale issues associated with high-speed failure phenomenon in heterogeneous materials, and particularly points out the revival of interest in this difficult area of experimental mechanics. The article has been prepared by Dr. Ares J. Rosakis who is a well known authority on dynamic failure of materials.

Dr. Rosakis is a Professor of Aeronautics and Mechanical Engineering at Caltech. Dr. Rosakis received his B.A. and a M.A. degree in Engineering Science - Oxford University; Sc.M. and Ph.D. degree in Solid Mechanics - Brown University. He is the author of over 120 works on quasi-static and dynamic failure of metals, composites, and interfaces with emphasis on dynamic fracture and dynamic localization. His recent interests include shear dominated intersonic rupture of inhomogeneous solids, rupture mechanics of crustal earthquakes, and reliability of thin films. His awards include: IBM Faculty Development Award; NSF Presidential Young Investigator Award; Rudolf Kingslake Medal and Prize from SPIE; Hetenyi and Lazan awards from SEM; Excellence in Teaching Award from the Caltech Graduate Student Council. He is a past Chairman of the Fracture & Failure Mechanics Committee of the Applied Mechanics Division, a Fellow of the ASME and the New York Academy of Sciences.

TRENDS IN EXPERIMENTAL MECHANICS

by Ares Rosakis



High Speed Failure Phenomena in Heterogeneous Material Systems at All Length Scales - A Revival!

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It only took a few years after the end of the Cold War for academic research on the mechanics of dynamic deformation and failure of structural materials to come to a virtual standstill. This situation lasted for a period of approximately ten years. However, recently several developments have contributed to the reversal of this trend. In particular, the introduction of new material systems and the development of mathematical maturity in the field of Geophysics, along with some spectacular experimental and numerical discoveries have all rekindled the interest in the ways that heterogeneous material systems, at all length scales, fail when subjected to dynamic loading.

In the 1970's and early 1980's, the dynamic failure of homogeneous structural solids was at the forefront of research activity while the charge was lead by leaps in experimental discovery. The important structural materials of the time were mainly monolithic (homogeneous) metal alloys and polymeric systems, which failed through the spreading of dynamic, mode-I (opening) cracks that multiplied (branched) through these systems at various sub-Rayleigh speeds. The exact failure initiation conditions and crack speeds were found to be dictated by the severity and rate of the applied loading, as well as by the dynamic fracture toughness of the material. In order to study such phenomena, the early experimental mechanicians utilized early forms of high speed photography and optical methods and thus visualized fast failure in real time while motivating theorists to construct elaborate models of dynamic crack initiation, growth, arrest, and branching. These models have formed the backbone of the basic science of dynamic fracture and fragmentation in homogeneous and primarily isotropic elastic materials.

It was indeed, at that stage of scientific development that the end of the Cold War's abrupt decrease in funding resulted in the dwindling of research activities. At that time, the experimental researchers were already beginning to abandon the idealized transparent and brittle polymer systems initially used as model materials and to develop high speed, high resolution, diagnostic methods that could, for the first time, deal with "real," non-transparent solids of structural significance (e.g, metal and ceramics). Unfortunately, these late successes were unable to turn the tide of disenchantment until more compelling technical and scientific needs for revisiting the subject of dynamic failure became, once again, apparent in relation to heterogeneous material systems and structures at all length scales.

Modern heterogeneous engineering materials systems and structures are developed by intentionally combining solids of various unique mechanical properties and by tailoring their interfaces so that such systems deform and fail in particularly desirable ways. Specific applications dictate the choice of the

Continued on Page 12

TRENDS IN EXPERIMENTAL MECHANICS

Continued from Page 1

homogeneous subcomponents and guide the tailoring of the interfacial strength so that the resulting "heterogeneous" composites exhibit special properties that are often very different than those of individual constituents. Examples of classes of such materials include layered or functionally graded structures, fiber or particle reinforced composites, frictionally held jointed structures, as well as thin film structures. At an entirely different length scale, geological materials containing interfaces in the form of faults offer yet another example of complex heterogeneous structures with great similarities to modern composites.

The basic characteristic differentiating such systems to traditional monolithic structures, from the specific point of view of dynamic loading and catastrophic failure, is the abundance of interfaces. It has been recently shown in the experimental literature that such interfaces often become favorable sites of highly unstable dynamic crack initiation and dynamic crack growth, which at times is even observed to be intersonic. Dynamically growing cracks are often trapped along these interfaces and can even propagate under specific combinations of compression and shear. It is noteworthy that this situation is never observed in homogeneous materials where cracks can only grow in mode-I opening. Dynamic (rate and state dependent) friction plays a significant role in this unusual shear dominated rupture process since it provides a dominant mechanism of energy dissipation that often dictates the overall failure properties of these heterogeneous systems. It is due to such recent experimental discoveries of unusual shear dominated rupture/friction processes that scientific interest in dynamic failure mechanics has been reinvigorated. Indeed, dynamic shear rupture of both coherent (intact) and incoherent (e.g., frictional) interfaces is a unique phenomenon by itself bearing only nominal similarities to its classical mode-I counterparts. Growing shear/compression ruptures may spread at extremely high speeds and become intersonic with respect to either or both constituents across an interface. They also exhibit an elaborate shear shock wave structure associated with their intersonic nature, as well as a complex crack face contact behavior whose characteristics can only be understood and modeled if appropriate dynamic frictional laws are employed. Surprising as it may sound, the intersonic nature of such failure may be triggered even under relatively mild impact conditions that are common to engineering environments.

In a totally different length scale, that of earthquake processes, similar situations may naturally occur within the earth's crust. Indeed, the spontaneous rupture of pre-existing earthquake faults is a dynamic rupture process that also occurs under a combination of quasistatic tectonic compression and shear. Most of such processes remain sub-Rayleigh, although recently field evidence of intersonic earthquake rupture has been reported in relation to the 1999 Izmit earthquake in Turkey. Depending on whether a fault is

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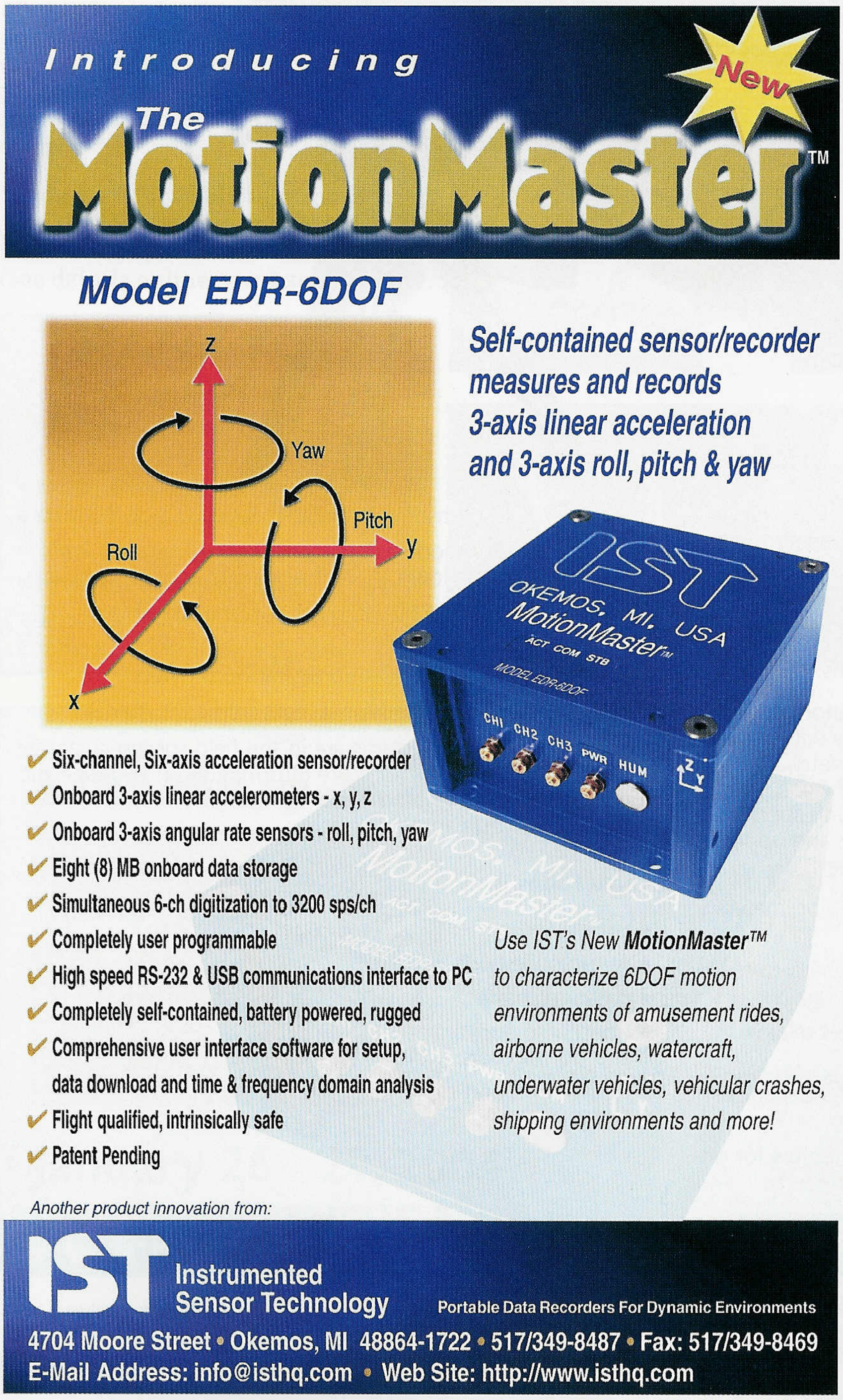

TRENDS IN EXPERIMENTAL MECHANICS

Continued from Page 12

either geologically "young" or "mature," fault planes may separate rock masses that are mechanically similar or dissimilar. These dynamic ruptures have traditionally been modeled as "large" shear dominated cracks propagating along prescribed paths in otherwise homogeneous solids or in bimaterials under the combined action of compression and shear. In such cases, the nature of dynamic friction and the resulting frictional dissipation becomes extremely important. In fact, the geophysical literature is dominated by theoretical and numerical predictions of inhomogeneous "pulse-like" rupture modes, which under certain circumstances are favored over the more classical "crack-like" rupture model. In the opposite extreme of length scales, recent atomistic simulations of shear rupture of atomic planes have demonstrated the existence of similar intersonic shear rupture phenomena at the nanoscale. Such an amazing length scale persistence of these processes (length scale span of 12 orders of magnitude) points to the scientific importance of the subject of dynamic shear rupture and, as a result, has recently captured the attention of solid state physicists.

The multiplicity of new dynamic fracture and friction phenomena characterizing the failure of heterogeneous solids at all length scales has already resulted in a renaissance in high speed experimentation. New high speed optical and infrared diagnostic techniques featuring submicrosecond resolution are currently being developed to study dynamic failure in all length scales and to measure both mechanical and thermal fields in full field and in real time. The purpose of these studies is to investigate the detailed nature of the inhomogeneous rupture and sliding processes and to develop a better understanding of dynamic frictional laws. In the discovery phase, dynamic experimentation has been and will remain crucial for the identification of new, and perhaps unexpected, physical phenomena to be subsequently modeled by theoreticians. Highly instrumental, high resolution (spatial and temporal) experiments will also be crucial to the systematic validation of elaborate dynamic numerical codes. Indeed, numerical methods applied to all length scales have come a long way in modeling the dynamic loading and deformation behavior of complex heterogeneous structures. However, the detailed physics that govern dynamic rupture and frictional dissipation is either missing or is often included in the form of very crude failure models that have not yet been validated in detail. The only hope of successfully completing the cycle of discovery, modeling, and validation are high resolution dynamic experiments. If truly predictive failure modeling is ever to become a reality, its role would be indispensable.■